

A Consensus on Powering and Grounding Sensitive Electronic Equipment

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Significance:

Part 6 – Textbooks, tutorials, and reviews

A paper presented to the IEEE Industry Applications Society Annual Meeting to support a proposal for developing a new standard in the Color Book series, "Powering and Grounding Sensitive Electronic Equipment," Standards Project P1100.

The effort was successful and an active Working was launched. The initial goal was to complete the project in four years. Unfortunately, the issues were sufficiently complex and opinions diverse to the point that the final "Emerald Book" IEEE Std™ 1100 was not completed until 1992, still a reasonable gestation period by comparison to some other IEEE projects.

One of the lingering issues was to clearly define "sensitive electronics." That ambiguity was resolved in the 1999 update by dropping out the qualifier "sensitive." It is also interesting to note that the 1999 update of the existing 1992 book took seven years, compared to the six years it took to start from the vision (a glimmer) described in this paper.

A CONSENSUS ON POWERING AND GROUNDING SENSITIVE ELECTRONIC EQUIPMENT

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Abstract — As sensitive electronic processing systems proliferate in our facilities so do power-related problems. Efforts to alleviate these problems have ranged from installing expensive power conditioning equipment to applying special grounding techniques not found in conventional safe grounding practice. Understanding of what is actually going on has been lacking. We find elaborate power systems, modified from basic practice to the extent of being unsafe, that continue to be plagued with powering- and grounding-related problems. Out of this chaos we are persuaded to study and understand the complexities of the problem and to begin developing good practices. This is the objective of the IEEE Working Group on Powering and Grounding Sensitive Electronic Equipment, Standards Project P1100. We will introduce Project P1100, preview its scope and technical content and, most importantly, invite participation in this seriously needed consensus standard activity.

INTRODUCTION

Powering and grounding sensitive electronic equipment is a growing concern for commercial and industrial power system designers. This concern frequently materializes after start-up when electronic system operating problems begin to occur. Grasping for power conditioning equipment or magic grounding methods is a common response. In some cases this course has led to unsafe practices and violations of the National Electrical Code without solving operating problems. Although good technical information is available, there is presently no consensus on recommended practice. This leaves responsible engineers to proceed from what they already know or can readily obtain in the literature. Unfortunately, there is conflicting information in the literature and, for most of us, the technical particulars are somewhat foreign to our power system design experience.

The concept of load and source compatibility is not new. The need to provide power with a steady voltage and frequency has been recognized since the inception of the electric utility industry. However, the definition of 'steady' has changed over the years, reflecting the greater susceptibility of increasingly sophisticated electronic equipment to the departure from 'steady' conditions. Some of the early concerns were flicker of light bulbs due to voltage variations and overheating of electromagnetic loads or interference of communication loads due to voltage waveform distortion. Recognition of these problems led to the development of voluntary standards which contributed significantly to reducing occurrences.

More recently, transient voltage disturbances associated with short circuits, lightning, and power system switching have emerged as a major concern to manufacturers and users of electronic equipment. Today's complaints about the quality of power are not easily resolved because they involve both a multitude of different causes and a variety of specific sensitivities in the affected equipment. Power system designers, utility companies, load as well as source equipment manufacturers, must cooperate with each other to find effective solutions. As in the past, voluntary consensus standards are needed.

The issue of grounding, in particular how to deal with noise and safety simultaneously, is complicated by conflicting philosophies advocated by people of different backgrounds. Power-oriented engineers and signal-oriented engineers often differ in their perception of common problems and solutions. One of the goals of the proposed standard is to promote better understanding of the real issues and to dispel some misconceptions on how to avoid or correct electronic system grounding problems.

Since the earliest days of electric power, users have counted on utilities to provide electricity that is as free as possible from outages, voltage surges, and harmonic waveshape distortions. Reducing such power line disturbances has always been a critical concern for utilities. Recently, however, new sources of disturbances have begun to proliferate, just as many pieces of equipment are becoming more sensitive to these same power disturbances. Some of these disturbances are generated by adjacent equipment, so that the utility supply should not be blamed for the occurrence. These developments have presented utilities and users with a new set of complex power quality issues that will require wide-reaching cooperative efforts to be resolved.

A commonly applied solution to power incompatibilities is to install interface equipment between the raw utility power and sensitive loads. Difficulties in assessing this need are: (1) the quantification of just how much downtime is power-related, (2) the subjective nature of estimating the cost of sensitive load misoperation attributable to power. The cost/benefit aspects of the problem can be addressed from the technical point of view in a standard, but detailed economic analysis and specific decisions remain the prerogative of the user allocating the resources. Focusing on the technical issues, dispelling misconceptions, and recommending sound practices can assist the user in making an informed economic decision.

With that goal clearly defined, the new IEEE Working Group, Project P1100, was formed to develop a consensus standard that recommends practices for powering and grounding sensitive electronic loads in commercial and industrial power systems. The document is currently at the first draft stage.

POWERING ELECTRONIC SYSTEMS

Powering an electronic system is fundamentally the same as powering any electrical system. Estimating the load, matching current and voltage requirements, or planning for future growth involves the same basic information. Similarly, designing an appropriate electrical distribution system, selecting and coordinating overcurrent protection, and assuring good voltage regulation makes use of the same engineering practices. Even the principles of availability and reliability can be applied to electronic loads in the same way as to any other load.

An excellent reference library available for designing commercial and industrial power systems of all types is the *IEEE Color Book* series. There are currently nine Color Books in the Series providing recommended practices. The objective is to assist in the design of safe, reliable, and economical electric power systems by providing the consensus of knowledge and experience of the contributing IEEE members. Project P1100 is intended to yield a new Color Book in the series, directed specifically at powering and grounding sensitive electronic equipment.

The Duration of a Disturbance Is Key to Its Impact.

Computers are just like motors or lights: when the power goes away, the electrical device quits, and when power is restored, it restarts. Of course, it is frequently integrity of the process rather than the actual device that we must concern ourselves with. If we lose power to one high speed conveyor being fed by another high speed conveyor, we can expect a mess somewhere on the factory floor. Likewise, a central processor controlling a check printer with a stack of sequenced commands in volatile memory will most likely be upset by the loss of power continuity.

The duration of loss of power continuity is the key factor in predicting if a process disruption will occur. A large freezer may be able to ride through an outage of several hours before cooling loss. We are allowed seconds to restore light in a hospital operating room. Data processing upset may occur in tens of milliseconds, or in cycles of 60 Hz ac power. An outage is therefore defined differently by different users and producers of electric power, sometimes creating an obstacle to communication between these interested parties. Utility companies and their power supply contracts will normally only address outages measured in minutes. They do not consider perturbations lasting a few seconds or less as the utilities responsibility. When customer equipment is more critical or more sensitive than the norm, they consider it the customer's problem. The special power quality and continuity requirements of a number of commercial and industrial loads are described in the *IEEE Orange Book* [1].

Data processing equipment susceptibility to short duration (cycle to cycle) breaks in power continuity should not be overgeneralized. First, a computer can ride through a short outage. It happens every cycle of the ac power sinewave. Second, computers should be no more sensitive to steady-state voltage variations than any other load. American National Standard C84.1 establishes steady-state voltage ranges that apply to

all equipment. Furthermore, harmonic distortion in the utility voltage has not been shown to have any more impact on electronic loads than on motors or relays. We conclude that if electronic loads have susceptibilities to power-line disturbances, they also have tolerances that may reduce the cost and effort required to protect them.

A profile of data processing equipment susceptibility (and tolerance) to variations in the source voltage, Figure 1, has been published in an IEEE 'Recommended Practice' [1], and a NBS 'Guideline' [2]. Presented as a "Typical design objective of power-conscious computer hardware designers", it is not a computer industry standard. However, as a typical susceptibility profile, it does demonstrate the useful feature of increasing equipment tolerance with decreasing duration of voltage perturbation. As a practical matter, there are more disturbances of short than long duration. So, by comparing actual disturbance data to this profile we begin to quantify our exposure to power-related problems.

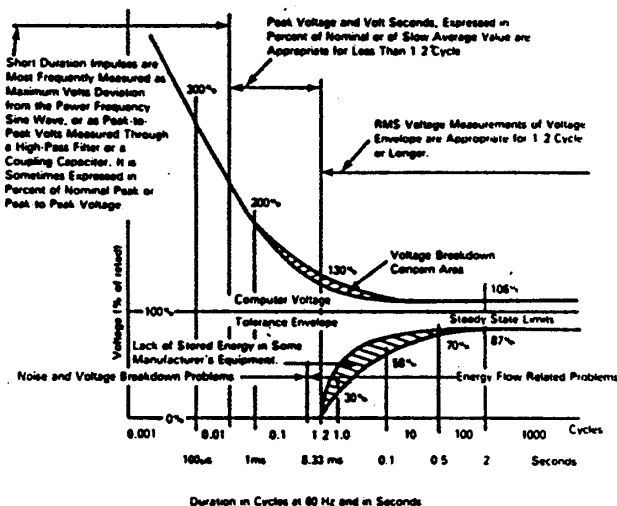


Figure 1. Typical Design Goals of Power-Conscious Computer Manufacturers.

Energy Analysis Is Useful in Diagnosing Power Problems

We can interpret Figure 1 from an energy flow viewpoint. On the right, we have limitations related to the wrong energy level occurring in the steady state. This limitation equates to a steady state voltage regulation problem. For cycle to cycle time intervals, our concern shifts to insufficient energy that occurs during an undervoltage condition resulting from common overloads or short circuits. In microsecond time domains, too much energy, in the form of a lightning or switching event generated overvoltage, surfaces as a practical concern.

This analysis can facilitate defining power-related problems in a way that leads to effective selection of power conditioning equipment or other appropriate corrective action. The first step is powerline voltage monitoring to determine site power quality. Once a site-specific power quality profile has been established and energy-related problems identified, one can proceed to single out appropriate power enhancement measures. For example, if intermittent undervoltages or sags are recorded, then interface equipment such as a motor-generator might be effective in riding through these shortages of energy. Further discussion of this method of diagnosis and prescription is found in [3].

The application of Figure 1 seems quite straightforward; however, solving a real-life power-related problem may not be. For one thing, the tolerance to overvoltage of several hundred volts, indicated in Figure 1, assumes an assault at the input to the computer power supply. The electronic equipment tolerance to overvoltages experienced in other locations may be significantly less. Noise coupled into the electronic system via many possible alternate paths, as compared to surges conducted along the power line, can disrupt data at a 5-volt logic level.

Related to the noise-coupling problem, is the attempt to apply Figure 1 in the presence of poor grounding or incorrect surge protecting of equipment. These mistakes may allow internally generated power-related problems that totally evade any power interface equipment installed, per Figure 1, to protect the site from the outside world. At the same time, such interface equipment will be adding cost and probably reducing overall power system reliability.

A systems engineering approach is required to properly address all aspects of the power- and noise-related problems. In Project P1100, we are attempting to present the best explanation possible of the myriad of power enhancement products and at the same time maintain a systems perspective. This perspective must include other critical elements of the power system, i.e. grounding and surge protection details, and installation procedures. We have found that grounding, discussed next, is a key to noise-related problems.

GROUNDING ELECTRONIC SYSTEMS

The subject of grounding is perhaps the most misunderstood, with the result that a large portion of the problems encountered in power supply applications originate from inappropriate grounding practices. An indication of the complexity of this subject is the fact that it occupies over five pages of the IEEE dictionary; no wonder misconceptions still abound. The existence of this problem in electronic systems can be explained by the different meanings attributed to the term 'ground' by the different specialists involved. Starting with the 60 Hz or power-frequency engineer, 'ground' is synonymous with 'earth'; its function is to provide a low-impedance path for return of power system fault currents to the generator. This low-impedance path serves a safety role by limiting voltage differences during system faults and by allowing sufficient fault currents to assure prompt tripping of the source circuit breakers.

In this context, ground connections are generally large copper conductors, offering low impedance to power-frequency current. Emphasis is given to the resistance of the connection to 'earth'--that is, the subjacent soil--by appropriate dimensions and number of driven rods in the earth, of buried counter-poise conductors, etc. The safety grounding system is passive and should not be called upon to carry rated current except during intermittent anomalies of power system operation such as short circuits. Occasionally, steady-state currents may be present due to device leakage or to the nearby influence of strong magnetic fields, for instance adjacent conductors of an arc furnace. Nevertheless, the steady-state current in grounding conductors should be relatively small when compared to phase conductor currents (NEC 250-21).

Both "Earthing" and "Referencing" Must Be Considered.

Shifting now to the electronic engineer, designing his data processing equipment, 'ground' is synonymous to

'chassis'. That is, the metal enclosure of the equipment, sometimes symbolically concentrated into a single shiny metal pad at the bottom of the cabinet, to which all connections to 'ground' are routed--and not always by the most direct route. His data processing circuitry involves analog or pulse voltage signals of generally less than 15 volts, or it involves current loops of a few milliamperes.

These signals can be transferred in a balanced, ungrounded circuit or a single-ended circuit with a common reference. Balanced circuits are isolated from ground but their voltage with respect to ground (common mode) is still significant to the operation and potential susceptibility of the circuits. Single-ended circuits carry signals referred to a common potential, most often that of the equipment internal chassis, generally called 'reference'. Thus, in either case it appears that the electronic engineer's concern is that his referencing system carries signal currents that can become polluted by spurious ground currents either through common connection points with the earthed system or by common-mode noise coupling.

Now enters the systems engineer responsible for the installation of the data processing system within one room of a building at best, or distributed among several buildings at worst: to him, 'ground' takes a double meaning. The first is the concept of the power system engineer, the second is the concept of the electronic engineer and, alas, they are not the same. If only the first had been called 'earth', and the second called 'reference', perhaps the designers would have coordinated their two distinctive requirements ahead of time and much on-site misery would have been avoided.

Instead, in the electronics engineer's case, the impedance of his 'reference' system includes a substantial inductive component because of the high frequency of the signal and noise currents. The large existing copper cables, suitable for earthing, are not suitable for referencing. A new ground reference grid providing a large number of different path links for the various noise frequencies will now have to be incorporated into the system.

So we see, for electronic loads, we have both safety and noise to concern ourselves with. Safe operation of an electrical or electronic system depends on the integrity and low impedance of its earthing. Undisturbed operation of the same systems depends on the geometry and intrinsic low impedance of its reference, regardless of the impedance between the reference and the earth [2].

The significance of reference and insignificance of earth connection can be illustrated by two examples: to prove its reality, consider that sophisticated equipment aboard an electronic countermeasures airplane are doing quite well, thank you, without an earth connection; back on the ground we find an illusion held by the system operator, confronted with interference and a referencing problem, when he contemplates and sometimes implements 'better grounding' by breaking up the concrete floor of the computer room to install additional ground rods.

The solution to this operator's problem is not 'better grounding', but better referencing--such as in the case of the airborne electronic system. On the ground level, the better referencing can be obtained by establishing a 'ground grid'. Here the major criterion is low impedance at high frequencies between any two points of the ground grid. Recall that the safety ground system should provide low impedance at low frequencies. In a computer room design, the 2'x2' grid

of a usual raised floor structure lends itself quite naturally to providing such a good reference. There are of course a few electrical design features that must be properly incorporated. References [2] and [4] already provide guidance for implementing this solution, and Project P1100 will extend the guidance to the status of a consensus standard.

Attempts at Noise or Surge Control Should Not Create Adverse Side Effects.

The first side effect is associated with the problem of circulating currents in the ground and reference conductors. Without question, these currents can inject parasitic signals into the data lines. This injection is common-mode noise coupling caused by unavoidable shared connection points between the power system ground and the electronic equipment chassis. The problem is real, the side effect is associated with how not to solve it.

There have been a number of apparently successful remedies such as sometimes obtained by opening up these 'ground loops', by creating a 'single point ground', by establishing a 'dedicated/isolated ground', and finally, in the ultimate language contradiction, by installing a 'floating ground'. All of these concepts, motivated by steady-state, low-level noise reduction theory, can and frequently do overlook the potential of power frequency faults.

Attempts to decouple equipment chassis from earth ground for the purpose of isolating and insulating often defeat the basic safety function of earth ground. They ignore safety and hardware damage issues associated with the relatively rare but potentially lethal situations occurring during power system faults and lightning surges. They also violate the National Electric Code as described in [5]; such practices should be eradicated!

Continuity of the green wire or metallic raceway grounding system is not incompatible with achieving effective noise control. Simply apply the principles of the ground reference grid discussed above and in [2]. Give careful attention to surge protection for both data and power lines as presented below. Don't resort to tampering with safety aspects of the grounding system to control noise. Finally, as a consulting engineer, called upon to correct power- or noise-related problems, beware of both the desire for and the existence of dangerous grounding practices.

Another adverse side effect is associated with the configuration and use of grounding conductors. It is the occurrence and conversion of what is called 'common mode' and 'differential mode' in multi-conductor systems. Initially defined in the context of communications circuitry, these two modes have been applied to ac power systems that include phase, neutral, and grounding conductors. Here a grounding conductor exists or is implied by the presence of earthed bodies. As with 'referencing', the situation is confused by the blurring of boundaries between signal processing technology and power delivery/system safety requirements.

Disturbances can occur in common mode but cures might be erroneously proposed that address only differential mode disturbances, or vice versa. Remedies to a differential-mode surge can create a common-mode disturbance. For instance, a frequently applied and very effective method for common-mode noise elimination is the installation of an isolation transformer. However, we should not expect this transformer to reliably attenuate differential-mode noise [6]. Conversely, the installation of a single protective device between

the phase and neutral conductors, at the end of a long branch circuit, will: (1) clamp the voltage between these two conductors, and (2) create a large voltage, akin to common mode, between the neutral and grounding conductors.

The appropriate solution, discussed in detail in Reference [7] for the case of a single-phase three-wire system, consists of providing an additional surge-clamping device between the neutral and grounding conductors. Project P1100 will address the polyphase as well as the single-phase situation.

With forethought, these side effects can be avoided. It is feasible to design a system where noise problems are successfully resolved without resorting to unsafe grounding practices. We have pointed out that a reference grid system may be economically incorporated in a computer room raised floor. Reference [4] describes how the reference grid approach, when used with computer power centers (isolation transformers) and surge suppression networks can successfully harmonize power and signal grounding requirements. In Reference [2] detailed guidelines are provided for computer room grounding. However, since these documents do not constitute a consensus standard, one major goal of Project P1100 will be to establish a consensus opinion by describing good practices as well as by citing erroneous practices that should be avoided.

SURGE PROTECTION

Power systems are exposed to external influences which can couple energy into the circuits, causing a momentary overvoltage or overcurrent, generally described by the term 'surge'. Internal switching of loads in these systems can also create these momentary events. Another phenomenon, the discharge of electrostatic charges that have built-up on the human body or objects, can also inject unwanted voltages or currents into electronic circuits. Finally, another threat is related to nuclear explosions effects, under the acronym of NEMP (Nuclear Electromagnetic Pulse). The proposed standard will address the first two of these surges, lightning- and switching-related surges.

Surges can have many effects on equipment, ranging from no detectable effect to complete destruction. In general, electromechanical devices withstand increasing voltage surges until dielectric breakdown occurs, while electronic devices can have their operation upset before hard failure occurs. With increasing surge levels, progressively more intense upset occurs, until breakdown takes place. If sensitive electronic data processing equipment should be protected from even the upsetting levels, it is axiomatic that damaging surges need to be dealt with before they propagate beyond the service entry for the computer room [7] and [8].

Definitions of the level beyond which transient over-voltages become a threat depend on the type of victim equipment or process. Where electromechanical devices can generally tolerate short duration voltages of twice rating plus 1000 volts, few solid-state devices can tolerate more than twice their normal rating. Furthermore, data processing can be affected by fast changes with relatively small voltage amplitudes compared to the hardware-damaging overvoltages.

Lightning Surges Can Strike in More Ways Than One.

Lightning surges on power systems occur in two modes: direct attachment of the lightning path to the power system conductors, and electromagnetic coupling of energy into the power system conductors by the radiation of a nearby lightning discharge.

Direct attachment injects the total lightning current into the system. The current amplitudes range from a few thousand amperes to more than 200,000 amperes. However, the rapid change of current through the impedance of the conductors produces a high voltage; most often this high voltage causes secondary flashover to ground, diverting some current even in the absence of an intentional diverter. As a result, equipments connected at the end of overhead conductors are rarely exposed to the full lightning discharge current.

Induction of surges by nearby lightning discharge is a less dramatic, but more frequent event. The resulting surge characteristics are influenced not only by the driving force--the electromagnetic field--but also by the response of the power system--its natural oscillations. This dual origin makes a general description of the occurrence impractical, but nevertheless a consensus exists on what representative threats can be expected in various physical environments [9].

Switching Surges Can Be More Damaging Than Lightning.

Whenever a circuit containing capacitance and inductance is being switched on or off, a transient disturbance occurs because the currents and voltages do not reach instantaneously their final value. This type of disturbance is inescapable and its severity depends on the relative power level of the load being switched compared to the power system in which the switching takes place. Most of these disturbances involve the response of the power system, just as in the case of induced lightning surges, so that in practice the surges observed within a building are similar in their diversity, regardless of their origin--lightning or switching.

More complex circuit phenomena, such as current chopping and restrikes, can produce surge voltages reaching ten times the normal circuit voltages, involving energy levels determined by the power rating of the elements being switched. These complex surges can have very destructive effects, even on rugged equipment, and must generally be controlled at the source rather than simply mitigated at the load [9].

Effective Protection Techniques Have Been Developed.

Survival or undisturbed operation of the equipment can be achieved in three manners: eliminating the cause of surges (for instance, eliminate lightning, switching, etc.), producing equipment immune to any level of surges, no matter how high, or, the obvious choice, finding the best economic trade-off where moderate surge withstand capability is built into equipment, and the worst surges occurring in the environment are reduced, by application of suitable protective devices, to a level which the equipment can tolerate.

Because the source of the surge is an energy transfer phenomenon, involving a current, any attempt at blocking or restricting this current by a high impedance series path will only produce higher surge voltages until breakdown occurs. Breakdown allows current in an uncontrolled manner, generally through an unwanted path. In contrast, a surge protective device, by diverting the current, offers a known, predictable and therefore harmless path.

This diversion of major surge currents is best accomplished in two stages. The first diversion should be performed at the entrance to the building, typically by a conventional surge arrester, such as a sparkover type device, rated for this duty [10]. Then, any residual overvoltage, resulting from the action of the service entrance arrester, can be dealt with by again diverting current with a secondary protective device.

For this secondary protection, we recommend a clamping type solid state device, installed at the power panel of the computer room, at the terminals of a connected load, etc. Figure 2 illustrates this coordination between two surge diverters and a series impedance.

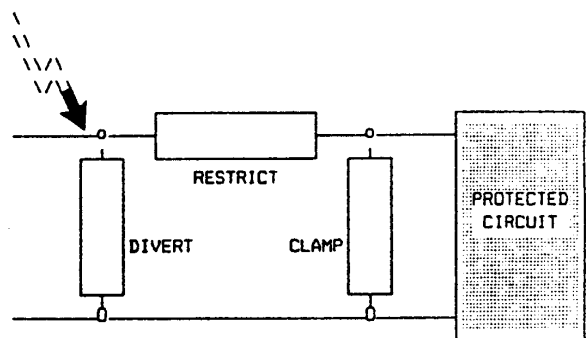


Figure 2. Two-Step Surge Protection for Power System Supply

A Need for Integrated Surge Protection Is Recognized.

An aspect of surge protection that might be overlooked is the need to provide an integrated approach to the protection of the power and data ports of an electronic system. A false sense of security might be created when surge protection is installed in the power supply and at the data entry and exit ports. However, unless the installation and ground connection of these protective devices have been correctly implemented, difficulties might still develop as a result of differences in ground potential rise during operation of the protective devices.

As an example, Figure 3 shows the case of a computer powered by the building supply on one side and interfacing with data lines from outside sensors on the other side. The power lines are protected at the service entrance and the data lines are protected at their entry point into the building. A surge impinging on the data lines and correctly diverted to ground at the entry point will unavoidably produce a rise in the potential at the 'ground' point where the data line protective device is connected, as compared to the 'ground' point where the power line protective

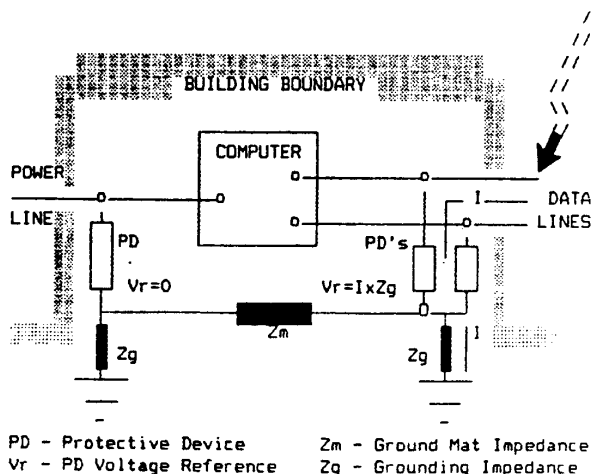


Figure 3. Differential Ground Potential Rise by Uncoordinated Application of Protective Devices

device is connected. The same difference of potentials would arise if the surge impinged on the power supply port. Thus, the 'ground' potentials on the power and data interface inputs at the computer cabinet will not be the same, leading to upsets or damage. This phenomenon is frequently to the dismay of the user who thought that adequate protection had been implemented with the two devices installed at the entry points.

In such an instance where the entry points are far apart, the solution consists in providing a secondary protective device for each port of entry into the computer cabinet (or entry to the computer room where the computer is installed on an equipotential plane or ground reference grid), and assuring the same point of 'ground' connection is used for these protective devices. While the qualitative aspect of this solution is gaining recognition, the quantitative parameters still need to be investigated. By the time Project P1100 nears completion, we expect that measurements, now in progress at the National Bureau of Standards, will contribute to the quantitative answer.

STANDARDS PROJECT P1100

We have thus far reviewed the need and some of the key issues that motivate us to recommended practices for powering and grounding sensitive electronic loads. In so doing we recognize that there are clearly many more details to address and many opinions and facts to reconcile. The following section will layout how we are currently proceeding in this effort. It is intended that enough detail BE provided to encourage discussion and feedback to the Working Group.

Approved Scope and Purpose of P1100

Project P1100 is titled "Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (A Color Book)". The IEEE technical sponsor is the Power Systems Engineering Committee of the Industrial Applications Society. A scope has been approved as follows:

"This project recommends design, installation and maintenance practices for electrical power and grounding (including both safety and noise control) of sensitive electronic loads such as computers, industrial controllers, and other electronic data processing equipment used in commercial and industrial applications."

Status of Project P1100

The standards project authorization request (PAR) was submitted in June 1985 and approved by the IEEE Standards Board in September. A 'strawman' outline for eleven chapters was developed and chapter objectives translated into a set of directives to chapter authors. Internal and external review procedures have been established. Preparation of a first draft is underway.

Meanwhile interest continues to grow. A number of tutorials have been offered both inside and outside of IEEE. As an apparent offshoot of deregulation, the utility industry is beginning to look at marketing a higher quality electric service with power conditioning equipment incorporated at increased electric energy rates. Still, there is no consensus standard available as a reference for electrical engineers responsible for the power system design. Help is needed in developing, writing, and reviewing this standard.

Proposed Chapters and Directives

- 1.0 INTRODUCTION - covers the purpose and background in much the same way as in this paper.
- 2.0 SCOPE - as quoted in this paper.
- 3.0 DEFINITIONS - this chapter provides definitions not otherwise available in IEEE Standards or as necessary to improve readability. The Chapter Chairperson is "Provost Marshal" with regard to use of undefined terms or acronyms in other chapters.
- 4.0 GENERAL NEED GUIDELINES - this chapter is intended to identify the relevant codes and standards as well as the existing electrical environment that sensitive electronic equipment is typically subjected to in the field. Topics include coordination with other guidelines, electrical safety, power quality, grounding, surge protection, life-safety, and telecommunication systems considerations. These guidelines are established as a basis for the treatment of performance requirements and recommended practices in subsequent chapters.
- 5.0 FUNDAMENTALS - this chapter introduces the reader to the fundamental technical information necessary to understand and to apply recommended practices for design of a compatible and essentially hazard-free interconnection. Fundamentals not unique to sensitive electronic and/or electrical equipment will be treated very lightly, or only by reference to other IEEE Standards and appropriate books on recommended engineering practice. Fundamentals to be covered include power system quality, electronic data processing equipment power quality requirements, load and supply compatibility, grounding bonding and shielding, protection, and wiring practices.
- 6.0 RECOMMENDED DESIGN/INSTALLATION PRACTICES - is the main message of this publication and is expected to be most difficult to gain consensus. Vagueness at this point would be a disservice to the reader. We intend to put down on paper our collective engineering experience and judgment to pinpoint recommended practices. The proposed subjects are general discussion on performance and safety, 60 Hz ac systems, 400-480 Hz systems, and life-safety system interfaces and controls.
- 7.0 NON-RECOMMENDED DESIGN/INSTALLATION PRACTICES - is the chapter in which we very deliberately attack "wives' tales" and raise "warning flags," but are careful not to introduce any new concepts or materials. Commonly observed non-recommended practices will be emphasized. The chapter is outlined by specific design topic to facilitate quick retrieval from the reference.
- 8.0 SPECIAL MEASUREMENTS AND INSTRUMENTATION - presents information on special measurement requirements and on available equipment that are unique to investigating and diagnosing problems in power systems that serve sensitive electronic equipment. The proposed approach is to start with dc measurements of voltage, current, and power and to progress through the fundamental frequencies (60 and 415 Hz) to harmonic and higher frequencies, up to 300 kHz. RFI/EMI will be covered by reference only.
- 9.0 SITE POWER ANALYSIS AND SITE SURVEYS - draws from the technical information base established in the

Table 1. Standards Coordination Plan

I. SPONSOR (WITHIN IEEE)	STANDARDS ACTIVITY	BASIS FOR COORDINATION
INDUSTRIAL APPLICATIONS SOCIETY		
-Power System Design SC	Red, Gray, and White Books	Basics of C&I power systems
-Emergency & Standby SC	Orange Book	General need, UPS/Batteries
-Grounding SC	Green Book	Safe grounding practice
-Reliability SC	Gold Book	Power system reliability
-Industrial Control Comm	IEEE Std 518	Needs of electronic controls
-Static Power Converter Comm	IEEE 519 "GUIDE"	Converter design/interface
POWER ENGINEERING SOCIETY		
-Power Generation Comm	P-678, IEEE 519 "RECD PRAC"	Grounding, noise control & UPS
-Transmission/Dist. Comm	ANSI C62,P-932	Service to critical loads
-LV Surge Prot. Device SC		Surge environment/testing
ELECTROMAGNETIC COMPATIBILITY SOCIETY		
-EMC Standards Comm	P-626	Signal grounding practice
II. SPONSOR (OUTSIDE IEEE)	STANDARDS ACTIVITY	BASIS FOR COORDINATION
NATIONAL BUREAU OF STANDARDS		
-Inst. for Comp Sci. & Tech	FIPS Pub #94	Electrical power for ADP
COMPUTER BUSINESS EQUIPMENT MANUFACTURERS ASSC		
-Power Interface SC (ESC-3)	Not a stds making body	Source of manufacturers data
NATIONAL ELECTRICAL MANUFACTURERS ASSC		
-Power Electronics Section	NEMA STD Pub/No. PE 1-1983	Uninterruptible power systems
UNDERWRITERS LABORATORY	UL # 478, 943 & 1449	ADP safety, transient tests
NATIONAL FIRE PROTECTION AGC	NFPA 70 & 75	Installation safety, fire prot.
INSTRUMENT SOCIETY OF AMERICA		Needs of instruments

previous chapters, and presents the practical aspects of problem diagnosis by an on-site engineer or technician. A section on interpreting and applying published power quality survey data is included; however, the chapter emphasis is the application of survey data from the user's own site.

10. SELECTION AND VERIFICATION OF EQUIPMENT AND MATERIALS - presents the myriad of available power enhancement equipment from a basic technology, performance, and functional point-of-view. A blend of manufacturer and user input is required. Manufacturers will be encouraged to provide generic rather than marketing details of equipment. How to verify equipment performance by testing is also covered.
11. CASE HISTORIES - is intended to provide explicit examples of real-world performance and/or safety problems that have been encountered in the field. Examples are chosen that did not conform, in one or more ways, to specific recommended practices presented in this publication. Special care will be taken to ensure that the selected examples are representing key-points of Chapters 6 and 7, rather than interesting, but obscure ones.
12. APPENDIX (as required)
13. ANNOTATED BIBLIOGRAPHY
14. INDEX

Coordination With Other Codes and Standards

As with most standards activities, there is a whole array of existing and proposed standards that are related to the technical scope. Careful coordination is critical to ensure proper treatment and avoid unnecessary overlap. Thus far we have identified or have been requested to coordinate with the activities listed in Table 1.

CONCLUSIONS

A consensus standard is needed for powering and grounding sensitive electronic equipment. This standard should not only organize and present recommended practices but also identify and dispel misconceptions

and discourage nonrecommended practices. Ahead of us is a tough and time-consuming job of sorting out various points of view and coordinating various other related standards activities. It will be several years before the task can be properly completed. This introductory paper is intended to be the first of several preceding publication of the consensus standard. The Project P1100 Working Group will welcome comments on the concepts presented in this paper and contributions to the final document.

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